meter only can be recommended for the present; all relative measures (i. e., measures taken with the actinometer) should be compared with this pyrheliometer exclusively. As an actinometer for regular use we can for the present recommend the Chwolson instrument".

The requirement that the relative actinometric measures be reduced to the above-named pyrheliometer exclusively implies, of course, that these actinometric values, as a whole, are capable of being thus reduced. The words "for the present" are added, because among pyrheliometers the Ångström compensation method and among actinometers the Chwolson construction naturally can have the exclusive preference only as long as no new instruments, more reliable, simple, and practical, are invented.

REPORT ON THE GREAT INDIAN EARTHQUAKE OF 1905.

By C. F. MARVIN, Professor of Meteorology. Dated September 14, 1907.

The above is the title of the latest issue of the Publications of the Earthquake Investigation Committee of Japan in Foreign Languages, Nos. 23 and 24, and comprises the elaborate and detailed report by Dr. F. Omori on the great earthquake which, at an early hour in the morning of April 4, 1905, Greenwich mean time, devastated a large section of northern India. The following is a summary of some of the many valuable points presented in Doctor Omori's report:

Origin.—The epifocal zone formed an elongated tract extending northwest and southeast for a distance of about 170 miles, approximately parallel to the trend of the subHimalayan chains of the Punjab. The geographic coordinates of strongest surface motion are considered to have been about longitude 77° E. and latitude 31° 49′ N. No great surface faulting or dislocation of the ground seems to have occurred or been manifest, and it would therefore appear that the origin of the disturbances must have been deep below the surface.[1] This conclusion is also suggested by a consideration of the wide extent of the region of sensible motion.

Intensity.—The earthquake was felt at an extreme distance of over 1000 miles, and serious damage was effected over a region of about 2150 square miles, an area slightly greater than that of the State of Delaware.

Omori states that "the total number of the houses destroyed in the Kangra district and the Mandi state amounted to 112,477, and the number of persons killed reached 18,815, exceeding any similar record of great seismic catastrophes in recent times"[2].

In connection with the great fatality of the Indian earthquake it is pointed out that the customary type of building within the stricken districts is constructed with walls of mud or rubble masonry, surmounted by heavy slate roofs, and is wholly unsuited to resist seismic action. In fact a massive, thick-walled house of inferior masonry work is shattered down at once by an earthquake shock into a heap of stone, with great loss of life to the inmates; whereas properly built wooden or steel-frame structures can resist almost any shock whatever.

The real measure of the intensity of earthquake action is the maximum acceleration of the vibratory motions of the ground at any place. In the absence of accurate automatic records this can sometimes be deduced approximately from various observed effects, and Omori gives the following values:

Upper Dharmsala: Maximum acceleration not greater than 2300 millimeters per second per second.

Kangra: Maximum acceleration not greater than 3500 millimeters per second per second.

Palampur: Maximum acceleration not greater than 2350 millimeters per second per second.

Mandi: Maximum acceleration not greater than 2280 millimeters per second per second.

In the great Japanese earthquake of 1891 the maximum acceleration in the Mino-Owari plain exceeded 4000 millimeters per second per second, and was much higher in the epicentral zone of the famous Neo Valley. Omori elsewhere states that the maximum acceleration in the San Francisco disturbance probably did not exceed 2600 millimeters per second per second. He also states that the minimum acceleration perceptible to the average individual is about 17 millimeters per second per second. It may be added that the acceleration of gravity at the surface of the earth, exprest in the same units employed above, is about 9800 millimeters per second per second.

Time of origin.—Seismographic records of the Kangra earthquake were not obtained anywhere within the zone of sensible motion. At Dehra Dun, however, about 120 miles southeast of the center of strongest motion, a valuable record for time determination was obtained on a magnetograph. This and similar records at Barrackpore, Kodaikanal, and Taungoo were carefully analyzed by Captain Thomas, in charge of the the magnetic department at Dehra Dun, and after eliminating, as far as possible, clock errors, etc., and allowing for the respective distances from the epicenter, the time of the beginning[3] of the earthquake at the epicenter was adopted by Omori as being 0^h, 49^m, 48^s, Greenwich mean time, April 4, civil reckoning.

Automatic records.—The major part of the report now under consideration is devoted to a detailed analysis and discussion of a large number of automatic records of the earthquake obtained at seismological observatories all over the world.

About 70 seismograms from 51 stations were available. A most valuable feature of the work is the reproduction, in original size, of 41 different seismograms from instruments of greatly varied type. These plates, with short explanatory text, constitute the material of No. 23 of The Publications. Not only are we able from these records to have before us a graphic picture of the earthquake motion at different places all over the world, but we are at the same time able to compare actual records from many different types of seismographs.

Results.—It is now generally known that unfelt earthquake motion as revealed in teleseismic records consists of several more or less sharply defined phases, or sections, and the analysis of the seismograms from this point of view has been carried out by Omori in considerable detail.

The record of an earthquake as it appears upon a seismogram is considered to have been produced at any given station by the arrival of earthquake motions propagated over the short, or minor, arc of the great circle passing thru the station and the origin. This primary motion Omori describes broadly as the W_1 motion, as distinguished from the motion which is propagated from the origin over the major arc of this same great circle, and which therefore must arrive later at the given station from the opposite direction This latter motion Omori calls the W_2 motion. Finally, he recognized a W_3 motion; this is the W_1 which, after passing the station, ultimately returns after completely circumnavigating the globe.

The W_2 and W_3 motions are generally superposed upon the so-called "end portion" or "tail" of the earthquake record, and are seldom sharply defined or clearly differentiated from the other features of the disturbance. Obviously, if a station is at a great distance from the origin, that is, near the antipodes, the motions propagated along the major and minor arcs must be very largely confused and superposed.

The primary motion (W_1) is subdivided by Omori into "first

[1] Probably not over 20 or 30 miles.—*C. F. M.*

[2] Excepting the north Japan earthquake of June 15, 1896, which caused great tidal disturbances along the northeastern coast of Japan, resulting in the death of 21,953 persons.

[3] In the Monthly Weather Review for April, 1907, p. 160, I have given reasons why the time of beginning of strong motion at the origin of an earthquake, and not the beginning of small tremors, should be regarded as the starting point for the discussion of long distance transmission of waves. In the present case we should conclude from the data employed that the strong motion at the epicenter began at about 0^h, 50^m, 08^s, Greenwich mean time.

and second preliminary tremors", "the principal portion", of which five phases, or sections, are recognized, and finally "the end portion".

Omori has deduced the following data for the Indian earthquake diagrams:

(1) The speed of propagation of the initial waves of the several phases of W_1 motion.

(2) The amplitudes and periods of the sustained wave motion and their occurrence and distribution over the different parts of the records of the W_1 motion.

(3) The speeds of propagation and other characteristics of the W_2 wave motion which it is assumed has been propagated along the major arc of the great circle joining a station with the origin of the earthquake.

(4) Finally, the transit velocities, periods of waves, etc., are deduced for the W_3 motion, that is, the motion first recorded after it has circumnavigated the globe.

The most distant station to record the earthquake was the Astronomical Observatory of Mexico at Tacubaya, distant 128° 39′ nearly north of Kangra, or on a great circle passing very nearly thru the pole of the earth; that is to say, in the opposite half of the meridian passing thru the origin.

There is a slight indication that the speed of propagation across the polar and low lying, or suboceanic, regions is a trifle higher than across mountainous Tibet and China to Japan for example; but this indication is offset by the practical identity of the transit velocity to north Germany and Great Britain, across plain regions, as compared with that over the mountainous path to south Austro-Hungary and northern Italy.

The mean transit velocities for the different phases of earthquake motion are summarized from Omori's report, pages 252 and 253, as in Table 1.

TABLE 1.—*Average transit velocities.*

Phase of motion.	Direct method.		Difference method.	
	Velocity.	Limits of epicentral distance.	Velocity.	Limits of epicentral distance.
W_1 motions:	*Km./sec.*	°	*Km./sec.*	°
First preliminary tremor	v_1 = 10.52	50–121	v_1 = 11.36	28–121
Second preliminary tremor	v_2 = 5.63	40–116	v_2 = 6.46	28–129
First phase, principal portion	v_3 = 4.07	47–129	v_3 = 4.70	39–129
Third phase, principal portion	v_5 = 3.11	39–129	v_5 = 3.28	39–129‡
W_2 motions:				
Commencement, W_2	5.00*	....	....	
First maximum, W_2	v_5 = 3.75*	....	....	
Principal maximum, W_2	v_5' = 3.34	....	v_5' = 3.39*	
W_3 motions:				
Principal maximum, W_3	v_5'' = 3.40	....	v_5'' = 3.40†	

* Propagated over major arc. † Circumnavigated the globe. ‡ Practically independent of distance from epicenter.

NOTE.—Velocities by the direct method are found by dividing the actual distance of a station from the epicenter by the difference in time of occurrence at the origin and the station, and are affected by any errors in location of the origin or in the time of disturbance. The difference method consists in dividing the difference in distance of stations by difference in time of arrival. The stations, in this case, should be approximately in the same lines of propagation.

Distance of origin.—The duration (y in seconds) of the first preliminary tremors recorded at any station is intimately related to the distance (x in kilometers) from the origin, since it represents how much time the fast moving first preliminary tremors gain on the slower moving second preliminary tremors when propagated over a given distance.

The results from 37 seismograph stations are given on page 183 of Omori's report, as in equation 1:

$$x = 13.77\, y - 576 \qquad (1)$$

The data for 10 earthquakes, all recorded in Japan, give equation 2:

$$x = 14.42\, y - 148 \qquad (2)$$

The San Francisco quake, recorded at many observatories, gives equation 3:

$$x = 16.79\, y - 1618 \qquad (3)$$

The Turkestan quake, recorded at a limited number of stations, and accordingly of less weight, gives equation 4:

$$x = 11.80\, y - 60 \qquad (4)$$

From the weighted mean of equations 1, 2, 3, and 4 Omori obtains equation 5:

$$x = 14.28\, y - 890 \qquad (5)$$

which may be regarded as generally applicable to miscellaneous stations at a distance of 20° to 140°, while No. 2 is more distinctly applicable to distant earthquakes, recorded at Tokyo.[4]

Omori finds the assumption that the motion is propagated along the chord leads to more complex and irrational results than are tenable.

Seismological apparatus.—Those who desire to know what sort of instruments are most suitable for earthquake observation will be interested in the following remarks by Omori, page 5, Publications of the Earthquake Investigation Committee in Foreign Languages, No. 23.

Function of microseismographs.—No single seismograph can record clearly all the different sets of the vibrations composing the earthquake motion, when the slow component is of a large amplitude. At least two instruments are required for the complete observation of the horizontal (or vertical) motion; the one, with a long oscillation period of 60 seconds or more, recording the slower component, and the other, with a short period of some 15 seconds, recording the quicker component.

To prolong the oscillation period of a horizontal pendulum, the following three conditions are necessary:

(1) The weight of the heavy bob must not be too great, as the point of support must always be kept very sharp.

(2) The length of the strut, or the horizontal distance between the point of support and the steady axis, must not be short.

(3) The height of the pendulum, or the vertical distance between the point of support and the point of suspension, must be made large.

With a horizontal pendulum set up in the "earthquake-proof house", which is 2.65 meters in height and whose strut was one meter in length, the oscillation period was raised to 3 minutes, the weight of the bob being 7½ kilograms.[5] By increasing the height and the length in question the oscillation period can, of course, be more lengthened.

For the observation of the W_2 wave, or the earthquake motion propagated along the major arc between the center of disturbance and a given station, and the W_3 wave, namely the repetition of that first propagated along the minor arc, or the shortest path, the friction of the instrument must be made very small, the oscillation period being made suitably long.

Seismoscope.—Altho the primary object of seismometry is to record correctly or absolutely the earthquake motion, sensitive seismoscopes are also invaluable in the researches on earthquake phenomena, especially in observing, (1), the small movements at the commencement of the first preliminary tremor, and, (2), the feeble vibrations of the W_2 and W_3 waves. The instruments best adapted to these two last-mentioned purposes would be, respectively, a horizontal pendulum of very small mass and of a high magnification, with an oscillation period of 3 or 4 seconds, and a similar one with an oscillation period of about 20 seconds; the registration being in each case made photographically. Instruments of

[4] If the transit velocities v_1 and v_2 in Table 1, in kilometers per second, are reliable, we should have, especially for long distance quakes:

$$y_1 = \frac{x}{v_2} - \frac{x}{v_1} = x\left(\frac{v_1 - v_2}{v_1\, v_2}\right),$$

from which, by substitution,

$x = 12.1\, y$ by the direct method;
$x = 15.0\, y$ by the difference method.

Milne gives the rule:

$$x = 13\, y_1.$$

Laska's rule is:

$$x = 16.67\, y - 1000.$$

Angenheister at Göttingen has used the difference in time of arrival $(T_1 - T_2)$ of the W_1 and W_2 motion for computing the distance of the origin by a formula of this form:

$$x = \text{semicircle of earth} - (T_1 - T_2)\, v,$$

in which v is the velocity of the W_2 motion, as given, for example, in Table 1.

The obvious discordance in these results is doubtless due to difficulties in identifying the several phases of motion and to errors in the assumption that the paths of the several wave motions are approximately proportional to the arcual or angular distances of stations from each other and the origin.

[5] See the Publications, No. 5; subsequently the weight of the bob was increased to 46 kilograms.

Professor Milne's type, with proper improvements, would, in this respect, prove very useful.

For the observation with such seismoscopes as above supposed there is no need for damping the motion of the pendulum, the object being to utilize the proper oscillations of the latter. A high magnification instrument with a large amount of friction fails to record satisfactorily the slow small vibrations.

RECENT ADDITIONS TO THE WEATHER BUREAU LIBRARY.

H. H. Kimball, Librarian.

The following titles have been selected from among the books recently received, as representing those most likely to be useful to Weather Bureau officials in their meteorological work and studies. Most of them can be loaned for a limited time to officials and employees who make application for them.

Agra and Oudh United Provinces. Meteorological reporter.
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Compte rendu de la 35me session. Paris. 1906. cxv, 387 p. 8°.

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Résumé des observations centralisées ... 1905. n p. n. d. 26 p. f°.

Georgetown (British Guiana). Botanic garden.
Meteorological observations 1906-7. n. p. [1907.] HHi-24. f°.

Great Britain. Meteorological office.
Hints to meteorological observers in tropical Africa, with notes on methods of recording lake levels ... London. 1907. 36 p. 8°.

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Schätzung der mittleren Niederschlagshöhe im Grossherzogtum Hessen im Jahre 1905 und Vergleichung der Niederschlagshöhen des Grossherzogtums im Jahrfünft 1901-5. Darmstadt. 1906. p. 59-64. 8°. (S.-A. Notizbl. Ver. Erdk. 4 Folge. Heft 27. 1906.)

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Die Phänologie ... Münster. 1895. 51 p. 8°.

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Klimatologische Probleme im Lichte moderner Seenforschung. (32. Jahresb. d. Gymnasiums. z. Neuhaldensleben. Neuhaldensleben. 1907.) 22 p. 4°.

Havana. Colegio de Belen. Observatorio.
[Report.] Año de 1906. Habana. 1907. v. p. f°.

Hertzog, August.
Die Weinjahre von Elsass-Lothringen in der Vergangenheit. Colmar. 1906. 86 p. 8°.

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Samuel Pierpont Langley. Washington. 1907. 49 p. 8°.

Württemberg. Königliche württembergische meteorologische Zentralstation.
Deutsches meteorologisches Jahrbuch. 1905. Stuttgart. 1907. 60 p. f°.

RECENT PAPERS BEARING ON METEOROLOGY.

H. H. Kimball, Librarian.

The subjoined titles have been selected from the contents of the periodicals and serials recently received in the Library of the Weather Bureau. The titles selected are of papers or other communications bearing on meteorology or cognate branches of science. This is not a complete index of the meteorological contents of all the journals from which it has been compiled; it shows only the articles that appear to the compiler likely to be of particular interest in connection with the work of the Weather Bureau. Unsigned articles are indicated by a ——

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